

# What Determines a Planet's Climate?



## TEACHER NOTES



*A curriculum project of the NASA Goddard Institute for Space Studies  
in collaboration with the Earth Institute at Columbia University.*

## To The Teacher

In order to make connections between science and education that can impact how science is taught and learned, a collaborative program at the NASA Goddard Institute for Space Studies was created to involve climate researchers, students, and teachers in the Institute on Climate and Planets (ICP). It is designed to foster joint investigations concerning actual research problems related to climate change and to enhance classroom learning and teaching with lessons motivated by this educational experience. ‘*What Determines a Planet’s Climate?*’ is a major project of the ICP. We also attempt to help interpret and implement national and state science standards by tying them to curricula based on research and scientific thinking skills in what we call *Research Education*.

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By the Institute on Climate and Planets

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# Introduction

## About 'What Determines a Planet's Climate?'

This module is designed to connect cutting edge NASA research with the teaching and learning of core science and mathematics concepts and skills while addressing state and national education standards. Since an important goal of research is creating new knowledge, the process of science inquiry and the research tools used to do research play a major role in all the lessons. Presented with a science problem, students seek answers and consensus by experimenting with physical and computer models, collecting and analyzing their own measurements, and conducting intercomparisons with real world data from satellites and ground-based observations.

NASA missions and related Earth and Space Science topics provide the real world problem context for student investigations. An important aim is for students to develop a scientific view that our environment is a system of human and natural processes that result in changes over various space and time scales. The authentic science experiences presented in this module are meant to develop life-long skills for thinking critically about a science problem and applying tools of science inquiry in new learning situations. This approach to learning and teaching considers the capacities students will need to develop in a workforce and society where science, technology, and public issues are increasingly connected.

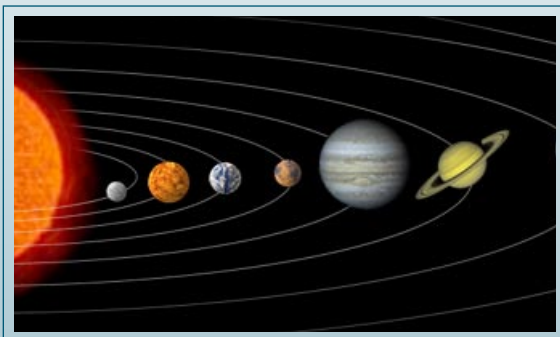
## The Science Research Context and Questions

What are some of the important factors that help regulate the balance of incoming and outgoing solar radiation? What is their role in creating an energy budget for Earth that produces habitable temperatures around significant portions of our planet where people live? How do these climate conditions compare to our neighboring planets Venus and Mars?

From space, we see Earth as a planet covered largely by blue oceans and white clouds. As the Earth orbits around this bright star, the sun emits enough energy to the planet to change the coolness of the night into the warming of the day around the globe. If we observe our planet from this vantage point



*What determines a planet's climate?*



*What is the relationship between planetary temperature and distance from the sun?*



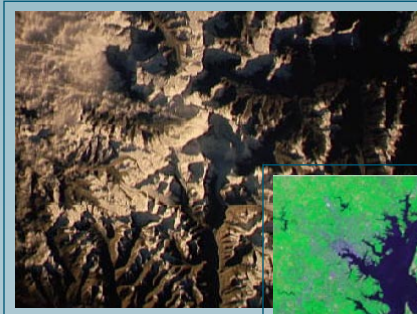
for the length of year, we begin to appreciate the global influence of the sun

Moving in for a closer look, we pass through layers of air in motion around the globe. Soon diverse surface features are visible revealing regions of deserts, ice and snow, mountains, rivers and lakes, and forests and other vegetation.

Nearing Earth's surface, evidence of human development on our planet's land surface can be found in patterns of city skylines, suburban sprawl, agricultural clearings, industrial complexes, and road systems.

Making similar direct observations of the human and natural influences on Earth's atmospheric composition is not as easy. We are able to detect the haze that can blanket heavily populated cities from gases emitted from power plants, automobiles and industrial facilities. In rural communities, a comparable dense haze can develop from dust or fires associated with clearing the land for farming.

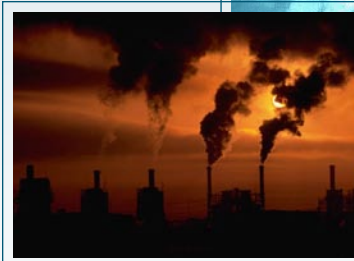
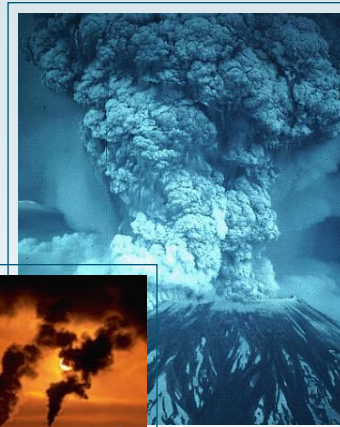
The research context and questions guiding this module help students develop an understanding of the human and natural factors that influence the composition of Earth's atmosphere and the reflectivity (albedo) of its surfaces. It engages students in an investigative process to learn how these factors help regulate Earth's energy budget. They discover how some factors warm Earth's climate by absorbing the sun's radiation while others produce a cooling effect by reflecting energy away from the planet. When they conclude with an examination of the greenhouse effect, students can draw upon the knowledge they develop in this module to begin to construct a system-level understanding of Earth's climate.



*How does the albedo of different surface features influence planetary temperature?*



*How do natural and human factors contribute to planetary temperature?*



*How does the greenhouse effect produce a habitable Earth temperature?*



### Topic 1: Temperature Variations and Habitability.

Students gain a perspective of the magnitude and range of temperatures that exist in diverse geographic locations on Earth and neighboring planets in our solar system. Hypotheses are formulated about factors that influence temperature, relationships between “inputs” and “outputs” in the Earth system that affect temperature and human- and natural-induced modifications in this system. These hypotheses will be the basis for students to design physical models and experiments for more in-depth studies of planetary temperature in Topic 2.

Initially, students investigate their immediate environment, proposing and collecting measurements with a variety of meteorological instruments to quantify their descriptions of indoor and outdoor conditions. Temperature data analysis and comparative studies are conducted on several planetary scales from the local environment to extreme regions on Earth to the nearby planets of Venus and Mars. This leads to an assessment of the magnitude and range of temperature variations that influence planetary habitability.



**Real World Problem: Searching for Life in Extreme Environments.**

**Topic 2: Modeling Hot and Cold Planets.** Students use a range of laboratory materials to construct planetary models and perform experiments to assess system behavior of variables such as distance from an energy source, and surface and atmospheric characteristics in producing planetary warming or cooling. This gives students a chance to evaluate the hypotheses they made in Topic 1 and to reject or defend their scientific claims. Independent and dependent variables are defined in each experiment, data is collected, graphed by hand and in a computer spreadsheet program, and analyzed for the importance of variables in influencing

planetary temperature. A computer modeling experiment simulates the physical experiment, leading to a discussion of the strengths and weaknesses of both tools.



**Real World Problem: Preparing for Mars Living in an Arctic Outpost.**

Students gain a conceptual understanding of how equilibrium temperature and surface reflectivity are related, leading into the scientific ideas of Radiation, the Inverse Square Law and the Law of Conservation of Energy. By using a global temperature data set from the Internet, students derive a value for Earth’s average temperature. In the process, they acquire an introductory understanding about

ground instrument networks and satellite observing techniques. They develop an appreciation for the quantity of average planetary temperature and accrue experiences dealing with data sampling and uncertainty associated with quantifying global climate.



**Real World Problem: Deforestation and Urban Heat Islands.**

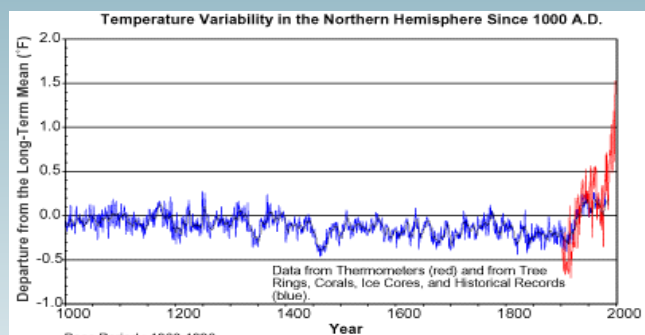
**Topic 3: Using Mathematical Models to Investigate Planetary Habitability.** Building on the conceptual understandings developed in Topic 2, students conduct another round of experiments using their physical planetary models to derive a mathematical description (equation) of the relationship between 1) sun distance and intensity of light reaching a planet surface, and 2) sun distance and surface temperature. The power of the computer spreadsheet is demonstrated when students plot their experimental data collected and find the “best fit” trendline (linear and non-linear). By generating the equation of the curve that best fits the data, students can derive the Inverse Square Law.

Provided with values for the luminosity of the sun and the solar constant, students produce their own computer model in a spreadsheet program to determine the incident energy and resulting surface temperature of a planet in our solar system. Theoretical black body temperatures of Venus, Earth, and Mars are calculated. A more complex model is introduced where students input regional albedo values (a measure of the amount of incoming energy reflected by a surface) obtained from NASA satellites to determine the average albedo of Earth and to study factors that influence planetary albedo on Venus, Earth, and Mars. Acting as scientific researchers, students use actual observations in the iterative process of model development and apply modeling tools to study relationships in Earth’s climate system. By the end of Topic 3, students will have compared planetary black body, average surface albedo, and actual planetary temperatures, setting the stage for considering atmospheric effects in Topic 4.

#### **Topic 4: How Do Atmospheres Affect Planetary Temperatures?**

Learning activities in this final topic are designed as a synthesis of student skills and understandings. A series of developmental projects help students explain the greenhouse effect and its contribution to planetary surface temperature.

Initially, students conduct a literature review to gain background knowledge on characteristics of the atmospheres of Earth, Mercury, Venus, and Mars.



**Real World Problem: Culprits of Climate Warming and Cooling.**

By comparing the effect of incident heat/energy on air versus the greenhouse gas carbon dioxide in a lab experiment, they formulate ideas and make predictions about the greenhouse effect. This leads to more in-depth knowledge about the ability of atmospheric gases to trap infrared radiation in the planet's atmosphere and the influence of this physical process on the planetary temperatures on Earth, Mercury, Venus, and Mars. Specific interactions between atmospheric gases (nitrogen, oxygen, carbon dioxide, and water vapor) and incoming and outgoing electromagnetic wave energy are the focus of a classroom simulation. By tracking energy inputs and outputs, energy budgets for three sun-planet systems are calculated.

Climate modeling activities give students a chance to test their greenhouse factor predictions and study the relative effectiveness of different variables in simulating the planetary temperatures on Venus, Earth, Mercury, and Mars. Magnitudes of derived theoretical values are compared to the observations from NASA missions. In another suite of modeling experiments they terra-form Venus and Mars by varying the four main factors investigated in this module – luminosity, distance from an energy source, albedo, and the greenhouse effect. Climate modeling scenarios are presented, debated, and defended.

### **Education Approach, and Science, Mathematics, and Technology Standards Addressed**

The current American science education reform movement advocates *Science For All Americans*. National education goals have created new benchmarks to prepare students with science literacy and habits that they can practically apply and that connect science, society, and technology.

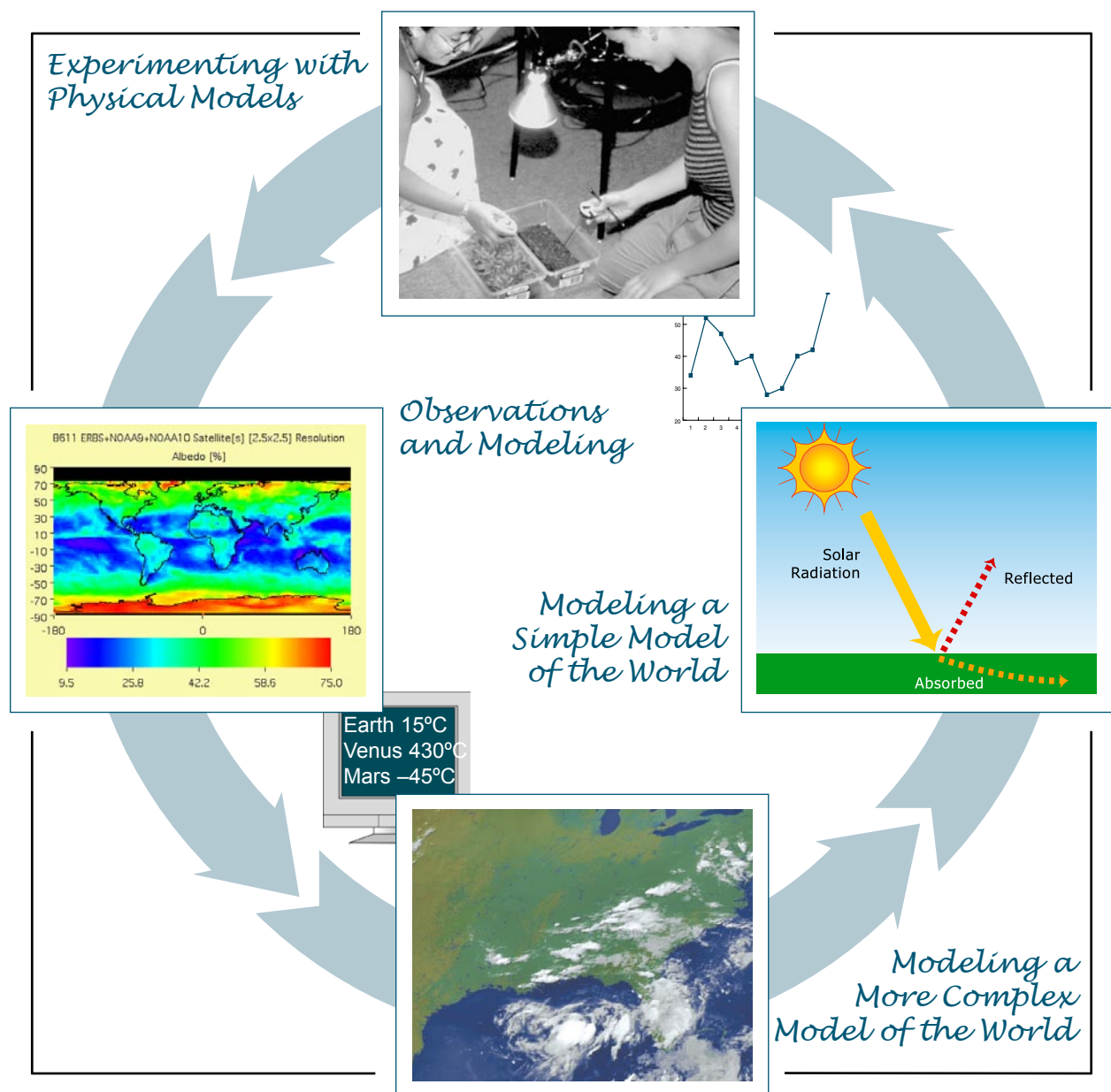
The National Council on Science has recognized that there are a number of common themes that cut across all science disciplines that help organize ideas and guide scientific inquiry. These themes are integrated into *What Determines A Planet's Climate?*, and include systems, models (physical, conceptual, and mathematical), stability and equilibrium, conservation, symmetry, patterns of change (trends, cycles, and chaos), evolution (possibilities, rates, and interactions), and magnitude and scale (AAAS, 1990). They also serve to organize science content into a structured body of knowledge that stands to make more sense to novice students, who can be easily turned off by scientific content because it often appears as a jumble of disconnected facts.

This course module addresses national science standards cited by the American Association for the Advancement of Science in *Project 2061* and by the National Research Council in *National Science Standards*, as well as the New York State *Science, Mathematics, and Technology Standards*. Many problems presented require reasoning about relationships between variables interacting in the Earth system. Students have a chance to develop hypotheses about these relationships and test them in experiments that develop their current understandings about how the world works.

Their analysis and interpretation draws on their own experimental data, as well data from NASA satellites and ground-based instruments. In the process, they evaluate the strengths and weaknesses of measurements. Various scientific tools are employed by students to design

and perform experiments that develop understandings about the Earth system's physical setting and living environment. This involves using both physical and computer modeling techniques. The computer models are particularly helpful in visualizing and evaluating physical processes.

Science concepts are learned through research where students build consensus about science results and prepare a synthesis of how they apply to over arching questions of relevance to science and society. In sum, the problems presented in this module translate many goals of science reform into a practical model, encompassing studies that are interdisciplinary, systemic, real-world problems, inquiry-driven, and thematically connected to the science, mathematics, and technology our students study. By giving students real scientific roles as NASA climate researchers, students can learn science by *doing* science.





## Organization of the Module

There are four main topics, each introduced by a Real World Problem. These Real World problems serve as an introduction to each topic and should be read by the students and discussed briefly before they begin the first activity. After completing all the activities in the topic, the students are asked to return to the Real World Problem and answer it from their new perspective.

Topic 1 gives students a chance to summarize their current understandings about factors influencing planetary temperature.

In Topic 2, they conduct experiments with physical and very basic computer models to build conceptual or qualitative understanding of relationships among selected variables that contribute to temperature of a planet.

By Topic 3, students are involved in quantifying these relationships with more advanced computer modeling tools.

The module concludes with Topic 4, introducing students to a more complex, quantitative system understanding of how energy interacts with surface and atmospheric characteristics to produce a planetary energy budget and greenhouse effect.

Science content background and skills are addressed in each topic through a series of investigations. They begin with a suggestion for how to engage students in a discussion about the relevance of the investigations and define their existing perceptions. Most topics have an activity where preliminary discussion and investigation planning can take place. While guidelines for the investigation procedures are provided, students are often asked to design some or all of the experimental tasks and roles. Data Sheets are included for them to record observations and data analysis. After completing the investigation, the class discusses their results and develops a consensus about what they have learned in the context of a suggested guiding question related to the topic's real world problem. Their interpretations and understandings of the science results are documented on pages titled Investigation Questions. The Investigation Questions and an Essay at the conclusion of each topic give students a chance for synthesis and assessment of what they have learned. The formats include multiple-choice questions dealing with key science concepts, constructed responses to explain how a physical process works and an essay to apply this knowledge to a problem. References are provided as resources for investigations and assessment questions.

## Evaluation of Student Work

At the end of each topic, a guide to evaluating student learning is provided. Investigation questions for each activity are followed by brief explanations of what to look for in their answers. These should be used in conjunction with the Learning Objectives listed in each activity to evaluate the understanding of science concepts.

# Syllabus

## Topic 1: Temperature Variations and Habitability

Activity	Learning Objectives	Science Skills
Real World Problem: Searching for Life in Extreme Environments	Self-assessment of students' knowledge of the habitability of environments.  Research based essay addressing the consequences of changing the factors that make the earth habitable.	Locate sources of pertinent information.  Evaluate data from sources.  Make inferences from selected data.
A: Observing, Describing and Adapting to Environmental Variations	Identify five factors useful in describing local environmental conditions.  State the range of temperature variability on the earth and in the solar system.  Relate the quality of life on Earth to temperature variability and our environment.	Observe and measure temperature and other characteristics of weather.  Compare values and identify sources of differences.  Identify ranges of variability.  Make hypotheses based on observed trends.
B: Relating Factors that Influence Planetary Temperature and Habitability	Give three examples of how humans modify the environment to improve livability.  Identify three factors that can determine the average temperature of a planet.  Identify five factors that may determine the habitability of a planet.  State the importance of maintaining habitable temperatures on a planet.  Describe the links between two factors.	Make observations of one's surroundings.  Organize information logically.  Explain the connection between related concepts.  Work with a team to form a consensus.  Communicate conclusions to others.  Evaluate the conclusions of others.

### Teacher Notes

## Topic 2: Modeling Hot and Cold Planets

Activity	Learning Objectives	Science Skills
Real World Problem: Preparing for Mars Living in an Arctic Outpost	<p>Evaluate the selection of Haughton Crater as a simulation of Mars.</p> <p>Apply concepts learned to describe facilities needed to make the site habitable.</p>	Analyze and critique scientific hypotheses as to their strength and weaknesses.
A: Modeling Hot and Cold Planets	<p>Design an experiment to answer a specific question and test a hypothesis.</p> <p>Differentiate between independent and dependent variables.</p> <p>Evaluate results and suggest modifications to an experiment.</p> <p>Prepare a synthesis of the experimental results to prioritize a set of parameters.</p> <p>Explain a conceptual relationship among temperature, energy inputs, surface features.</p> <p>Describe the strengths and limitations of physical models.</p>	<p>Develop testable hypotheses.</p> <p>Plan and implement investigative procedures.</p> <p>Select equipment and technology appropriate for the investigation.</p> <p>Share duties with team members.</p> <p>Collect data.</p> <p>Organize and analyze data.</p> <p>Present results clearly and logically.</p> <p>Evaluate experiment results of others.</p>
B: Experimenting With Computer Models	<p>Describe an equilibrium temperature.</p> <p>Identify the factors leading to an equilibrium temperature.</p> <p>Relate the temperature of an object to the energy it emits.</p> <p>Relate the temperature of an object to the reflectivity of its surface.</p> <p>Identify major energy inputs and outputs of a system.</p> <p>State and apply the Law of Conservation of Energy.</p> <p>Qualitatively relate distance from the source to the energy incident upon a body.</p> <p>Describe the strengths and weaknesses of computer models.</p>	<p>Use a computer model to simulate real world phenomena.</p> <p>Design and perform experiments with a computer model.</p> <p>Organize and analyze data.</p> <p>Evaluate the effectiveness of a computer model in simulating real world phenomena.</p> <p>Analyze the effect of changes on a system in equilibrium.</p>
C: Approximating the Average Surface Temperature of the Earth (optional)	<p>Utilize a data source from the Internet.</p> <p>Determine average temperature of Earth.</p> <p>Specify the characteristics of a sampling necessary to achieve an accurate average.</p>	<p>Find an appropriate source of data not easily obtained in a laboratory.</p> <p>Select a random set of values to determine an average.</p> <p>Evaluate the amount of data needed to achieve a reliable result.</p>



## Topic 3: Using Mathematical Models to Investigate Planetary Habitability

Activity	Learning Objectives	Science Skills
Real World Problem: Deforestation and Urban Heat Islands	<p>Describe how humanity can change the albedo of the earth.</p> <p>Describe how these changes may effect global and local temperatures.</p>	<p>Evaluate the effect of humanity on the environment.</p> <p>Draw inferences based on data.</p>
A: Finding a Mathematical Description of a Physical Relationship	<p>Make measurements with a voltmeter.</p> <p>Produce a graph using a spreadsheet.</p> <p>Determine the best fit for data using a spreadsheet.</p> <p>Quantitatively relate distance from the source to the energy incident upon a body.</p> <p>Quantitatively relate temperature of a body to the distance from a source of energy.</p> <p>Use the derived relationships to predict observed values.</p>	<p>Develop testable hypotheses.</p> <p>Plan and implement investigative procedures.</p> <p>Share duties between members of a team.</p> <p>Collect data and make measurements with precision.</p> <p>Use observed data to find a mathematical relationship between the variables.</p>
B: Making a Simple Mathematical Model	<p>Make an Excel spreadsheet model to determine the temperature of an object given its distance from an energy source.</p> <p>Compare theoretical black body and observed temperatures for a planet.</p> <p>Describe three advantages to using mathematical models.</p> <p>Describe three disadvantages to the use of mathematical models.</p>	<p>Use a variety of tools to analyze data.</p> <p>Use relationships observed in a system to model that system.</p> <p>Make predictions based on the model.</p> <p>Evaluate the effectiveness of the model.</p> <p>Determine the type of model appropriate for an investigation.</p>
C: The Role of Actual Data in Mathematical Models	<p>Read and analyze an albedo map of the earth.</p> <p>Determine the average albedo of the earth.</p> <p>Utilize the GEEBITT spreadsheet model.</p> <p>Compare theoretical and observed gray body temperatures for a planet.</p> <p>Suggest further improvements to the spreadsheet models.</p>	<p>Evaluate and make inferences from a data set.</p> <p>Use real world observations to modify a model.</p> <p>Evaluate the modifications of the model.</p>

### Teacher Notes

## Topic 4: How do Atmospheres Affect Planetary Temperatures?

Activity	Learning Objectives	Science Skills
Real World Problem: Culprits of Climate Warming and Cooling	On Earth, we know both human and natural activities play roles in the climate system. A major challenge facing climate researchers is to identify significant relationships between these factors and explain their influence on climate in ways that are objective and useful.	Synthesize data from various sources to determine significant relationships in terms of magnitude and scale  Develop scientific claims that can be supported in research results  State claims in a context that can be understood by the public and policymakers
A: How do Atmospheres Interact with Solar Energy?	State that an atmosphere has an overall warming effect upon a planet.  Describe the major characteristics of the atmospheres of Venus, Earth, and Mars.  State that the magnitude of the warming effect depends upon specific characteristics of the atmosphere.  Observe and measure the temperature changes of gases exposed to light.  Identify this warming ability of the atmosphere as the Greenhouse Effect.  Briefly describe how an atmosphere produces the Greenhouse Effect.	Compare real world and model observations in order to make hypotheses about the real world problem.  Perform a literature (library and/or Internet) search to determine the current state of knowledge about a science concept.  Make observations and collect data from a physical experiment.  Relate the results of the experiment to the previously made hypotheses.  Describe key science concepts in one's own words.  Come to a preliminary consensus with other investigators as to the best explanation for a physical phenomenon.
B: How do Atmospheres Produce their Effect Upon Surface Temperatures?	Describe the effect of nitrogen and oxygen in the Earth's atmosphere on incoming and outgoing electromagnetic waves.  Describe the effect of carbon dioxide and water vapor in the Earth's atmosphere on incoming and outgoing electromagnetic waves.  Define "greenhouse gas" and explain its effect on the surface temperature of a planet.	Make observation and collect data from a simulation.  Relate the results of the simulation to real world phenomena.  Relate the characteristics of electromagnetic waves to their properties.  Modify a description of a phenomenon based upon new knowledge.

C: Can we Model an Atmosphere's Effect Upon a Planet's Surface Temperature?

Use the characteristics of a planet's atmosphere to estimate the magnitude of the Greenhouse Factor for that planet.

Use a mathematical model to determine the Greenhouse Factor for a planet.

Relate the Greenhouse Factors from the models to the actual conditions of the atmospheres of the planets.

Summarize the characteristics of the Greenhouse Effect.

Use a mathematical model to simulate real world conditions.

Use the experimental results of the mathematical model to make hypotheses about the real world.

Use real world observations to evaluate these hypotheses.

Come to a consensus with other investigators as to which hypothesis is the best so far.

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D: Can Venus and Mars Be Made Habitable?

Demonstrate the ability to manipulate GEEBITT.

Use GEEBITT to determine if there is a combination of the four major factors that can produce habitable average surface temperatures for Venus and Mars.

Debate the feasibility of terraforming Mars and Venus.

Relate the knowledge obtained in this module to the quality of humanity's future on the Earth.

Plan and implement an investigation using a mathematical model.

Collect data and make measurements with care.

Propose a feasible solution to a real world based upon a model simulation.

Defend the solution with logical and science based arguments.